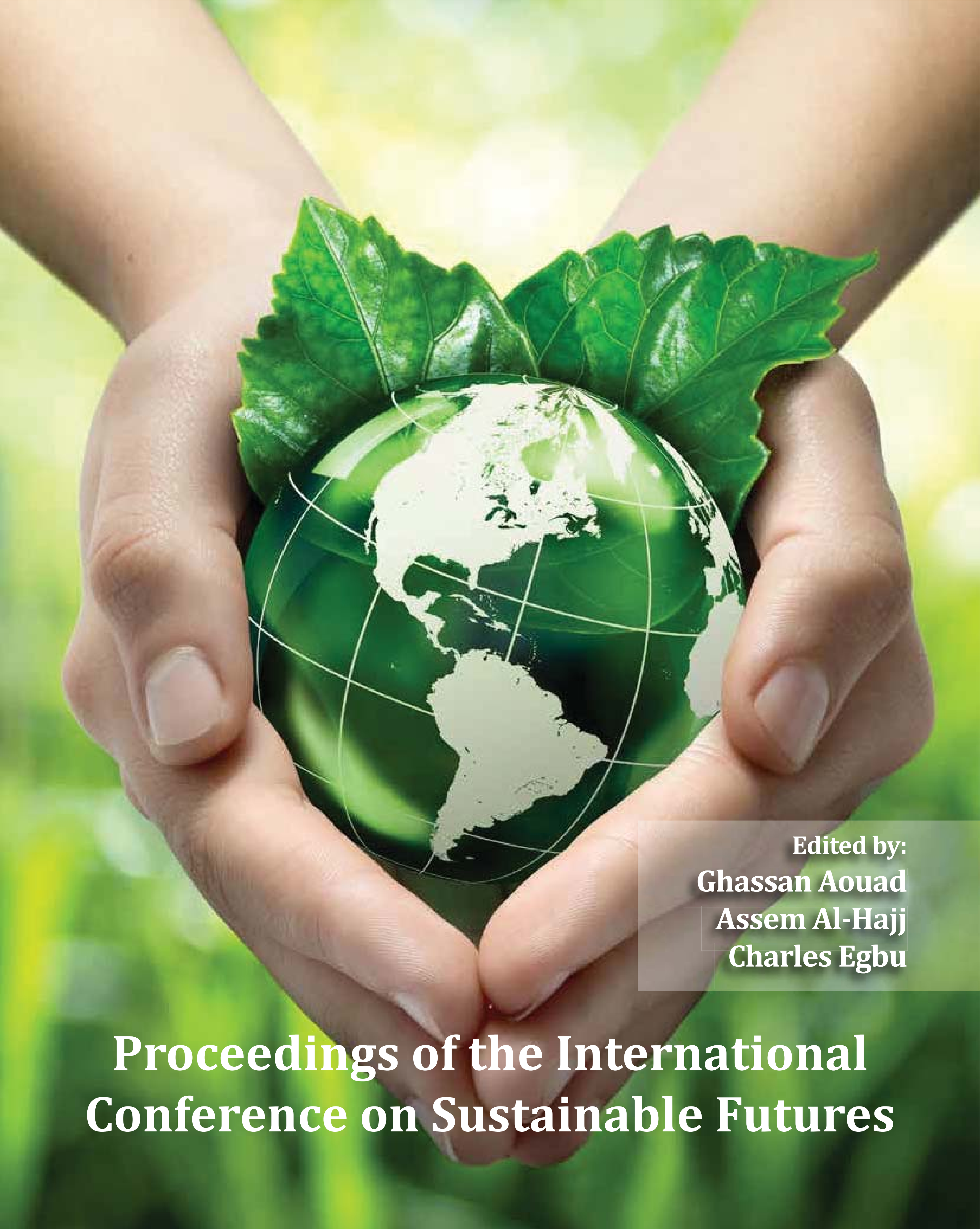

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Pervasive Augmented Reality in the Construction Industry: Barriers, Drivers and Possible Applications

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Abstract

Augmented Reality (AR) represents a viable and efficient approach for combining Virtual Reality with the real world. It also augments user's perception of a real-world entity by inserting relevant digital information into the real environment and creating an environment where computer generated information is superimposed onto the user's view of a real-world scene. The idea of Pervasive AR (PAR) adds context-awareness and continuity to the typical AR technology, thus providing continued assistance to the users. This paper is aimed at main drivers and barriers for the implementation of PAR within the field of Architecture, Engineering and Construction (AEC). A review of the literature was performed highlighting the main barriers and drivers for the implementation of PAR in the AEC sector, as well as possible applications of this technology. The literature review showed cost of technology, hardware issues and development of applications as the main barriers for implementing PAR. Whereas, error and cost reduction; and continued assistance were the main drivers of implementation. Although there are some barriers to overcome, the future implementation of PAR in the construction sector looks promising with possible applications of this technology in the AEC sector such as visualisation of spatial, drawing or technical information for designers, the jobsite workforce or marketing purposes.

Keywords: Augmented reality, pervasive augmented reality, construction industry, AEC sector.

1. Introduction

AR represents a viable and efficient approach for combining virtual reality with the real world (Kamat, *et al* , 2010). AR augments user's perception of a real-world entity by inserting relevant digital information into the real environment. Similarly, Chi *et al* (2013) explain AR creates an environment where computer generated information is superimposed onto the user's view of a real world scene. Simple AR solutions are marker based; this means that rely on markers to locate the overlay information on the screen. More robust solutions are context-aware, this means that they provide relevant information to the user based on the user's task and context.

According to Abowd et al. , (1999) context can be defined as:

> *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."*

This definition makes it easier for an application developer to enumerate the context for a given application scenario. If a piece of information can be used to characterise the situation of a participant in an interaction, then that information is context. According to Hong, et al., (2007) context can be classified into preliminary, integrated and final context. Preliminary context refers to raw sensor measurements, whereas integrated context encompasses inferred information from distinct sensors; Final context addresses information processed by the application, which tries to generate a higher level of understanding about the user's behaviour. Although this categorization divides context into a three-level scheme, ultimately context derives from the device's sensors. Hence, context-aware applications try to understand what the user is doing by using information obtained from sensors.

To be more specific, Abowd et al. , (1999) established a context-aware system as follows:

> *"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task."*

The application of visualisation techniques such as AR for planning, analysis, and design of Architecture, Engineering, and Construction (AEC) projects is relatively new compared to the sizeable amount of AR-related research conducted for diverse applications in fields such as manufacturing, medical operations, military, and gaming (Agarwal , 2016).

Recent investigations suggest that the implementation of AR applications in the AEC require the development of Pervasive AR solutions (Grubert*, et al* , 2017). Pervasive AR is a continuous and pervasive user interface that augments the physical world with digital information registered in 3D, while being aware of and responsive to the users' context (Grubert*, et al* , 2017). Moreover, Pervasive AR is the integration of context-awareness, responsiveness and continuity into traditional AR. This study presents the main barriers in the implementation of pervasive AR in the AEC sector, as well as possible applications of this paradigm. The findings are based on a critical review of the literature which is explained in section 0.

2. Background

2.1 Development of context-aware augmented reality in the AEC sector

One of the first attempts to develop an AR system solution was Sketchan+. It is an experimental tool which made a first attempt to use AR in the early architectural design stages. This AR prototype utilised a scribbling interface through the metaphor of a digitizer tablet and provides a 3D sketch as a virtual response. The next generation of sketchand+ is BenchWorks, developed as an AR prototype for analysing representational design in an urban design scale, which focused on techniques and devices necessary to create 3D models for urban design. The system was designed as a workbench, which combined optical tracking (the use of ARToolkit) with magnetic tracking. Another AR system derived from ARToolKit was developed by Dias, *et al.,* (2002), which provides a Mixed Reality system (MIXDesign) specifically for implementing tasks in architectural design, which developed tangible interfaces using ARToolkit patterns on a paddle and gestures.

Table 1 Timeline of context-aware AR research projects for the AEC sector.

Year	Contribution	Author
2006	Presented various case studies to illustrate the concept of context-aware service delivery within the AEC sector	(Anumba and Aziz , 2006)
2007	Used AR to assist in the training of operators of heavy equipment	(Wang and Dunston , 2007)
2007	Used AR to develop a cooperative reinforcing bar arrangement support system	(Yabuki and Li , 2007)
2008	Discussed the importance of location in context-awareness. Location aware apps can utilise the knowledge of the user location to provide relevant information.	(Behzadan*, et al* , 2008)
2008	Investigates constraints related to construction sites for the implementation of accurate calibration methods for multi-range AR systems.	(Shin, Jung and Dunston , 2008)
2009	Used AR to display 4D models used for managing construction activities	(Golparvar-Fard*, et al* , 2009)
2009	Used AR to display the positioning and layout of underground infrastructure and to mitigate undesired damages.	(Schall*, et al* , 2009)
2009	Presented research that investigated the effectiveness of three wireless technologies for dynamic indoor user position tracking	(Khoury and Kamat , 2009a)
2009	Investigated algorithms for identification of contextual data in location-aware applications, based on a dynamic user-viewpoint tracking scheme in which mobile users' spatial context is defined by position and three-dimensional head orientation.	(Khoury and Kamat , 2009b)

2013	Developed a low-cost mobile AR-based tool for facility managers which reduces data overload inefficiencies and enhance situation awareness	(Irizarry, *et al* , 2013)
2013	Presented a mobile AR system which enables a project's workforce to query and access 3D information on-site by utilising photographs taken from standard mobile devices. The user's location is derived from a 3D point cloud model generated from a set of pre-collected site photographs which is compared agains the users's images.	(Bae, Golparvar-Fard and White , 2013)
2015	Measured the potential used of AR in civil engineering and compared to other technologies	(Meža, Turk and Dolenc , 2015)
2016	Examined the concept of AR and its various implementations in Civil Engineering.	(Agarwal , 2016)
2017	Presented the concept of Pervasive Augmented reality.	(Grubert, *et al* , 2017)

There are several noted efforts towards collaborative AR systems in design and planning. For instance, Wang *et al.* (2003) developed an intuitive mixed environment called Mixed Reality-based collaborative virtual environment (MRCVE) to support the collaboration, design and spatial comprehension in collaborative design review sessions. The environment could be for mechanical contracting, face-to-face manner or distributed over a network.

Some investigations are focused on to the utilisation of AR technologies to address problems in the fields of AEC. Table 1 shows various research projects oriented to provide cyber-information to field personnel through mobile devices and AR systems. Some of these investigations have primarily focused on using Global Positioning Systems (GPS), Wireless Local Area Networks (WLAN), or Indoor GPS for accurately positioning the user within congested construction environments. Meanwhile, others have attempted to implement AR to help with heavy equipment operations. A common conclusion of these investigations is the positive effect obtained by the integration of AR in one or several processes of the AEC sector.

2.2 Conceptualisation of pervasive augmented reality

The first step in traditional AR is tracking and registration, which according to Chi, *et al.,* (2013) determines where to display digital contents. Initially, tracking and registration were performed using marker-based tracking toolkits. For designing various marker based applications, different toolkits such as ARTag, ARToolKit and ARToolKit Plus are utilised. ARToolKit is open sourced, easy to configure, well-documented and widely used in AR applications. Also, it has less execution time than ARTag and ARToolKit Plus Khan, *et al.,* (2015). Nevertheless, although ARToolKit is a simple toolkit, its users still have several problems in their attempt to achieve high quality and robust tracking of the markers.

With the rise of mobile and wearable devices, the increasing availability of geo-reference and user generated data and the accessibility of high speed; the construction industry counts with the right scenario for implementing AR technologies based on real-time data (Grubert*, et al* , 2017). This enables the users of AR systems to interact with their surroundings instantaneously.

Current AR applications usually serve a single purpose and are used only for short times. Standards used in AR hardware and sofware prevent a continuous, multi-purpose usage of the interface. However recent developments on head-mounted AR products have enabled a continuous AR experience. Grubert, *et al.,* (2017) refers to the concept of continuity in AR experience as "pervasive augmented reality" addressing it as a continuous, omnipresent and universal augmented interface to provide information in the physical world. Furthermore, it is defined as follow:

"Pervasive Augmented Reality is a continuous and pervasive user interface that augments the physical world with digital information registered in 3D while being aware of and responsive to the user's context."

Consequently, Pervasive AR derives from the addition of context awareness and continuity to typical AR.

2. Research methodology

This study is aimed at exploring the key features of pervasive augmented reality within the scope of the AEC sector across the literature. This section presents the methodology used to select the most appropriate research publications covering the topic of pervasive AR in the AEC sector.

This paper follows a systematic approach for reviewing compendium of literature to explore the current research in this field. The search for peer-reviewed journal articles has been done via databases. The literature was searched using the online service Google Scholar. The main advantages of these services are ease of use and a relatively broad universe of cited and citing items (Franceschet, 2010). To establish a search timeframe the trends of web search popularity for the term "Augmented reality" was obtained from Google trends. As can be appreciated in Figure 1.

The term "Augmented reality gained popularity in the transition of the year 2008 and 2009. Based on this data only publications between 2007 and 2017 were considered. Two searchers were made with the keywords "Augmented reality AEC" and "context-aware augmented reality". The selection criteria were indication of AR and construction in the title or abstract. The publications considered were open access journals within the category of original research or review.

Figure 1 Interest over time according to Google trends since 2007 for the term "Augmented reality".

Following the guidelines of (White and Marsh , 2006) a systematic content analysis was performed to create themes for main barriers, drivers and applications of AR in the construction industry. Once these themes were identified, they were analysed and presented in section 4.

3. Findings and discussion

This section presents the barriers, drivers obtained from the literature for implementing pervasive AR in the construction industry. Also, possible applications are categorised and presented.

3.1 Barriers to the implementation of pervasive AR

3.1.1 Cost of AR technology

Being a relatively new concept, the initial costs of setting up an AR system in place can increase the costs of the projects (Agarwal, 2016). An increased cost would cause a negative acceptance among the decision makers of the project.

3.1.2 Hardware issues

The main goal of AR applications is to overlay virtual information on top of real world objects. AR applications need to create the perception that simulates that virtual and real entities coexist in the same space with an adequate spatial alignment of real and virtual entities, without proper registration, this perception is compromised (Agarwal , 2016).

Size and weight represented another important issue to consider (Azuma*, et al* , 2001). Nowadays Smart devices allow user to implement AR-based applications with mobility. Others head mounted displays like the Daqri Smart helmet and HoloLens are aiming to provide a mobile solution for the manufacturing and construction industry (Greenhalgh*, et al* , 2016).

3.1.3 Development of applications

The development of user-friendly applications that abide to the right paradigm of context-awareness and pervasiveness is an important barrier for implementing pervasive AR solutions. With the field of AR being very vast and diverse companies need to consider developing applications specifically for the AEC sector.

3.2 Drivers

3.2.1 Error and Cost reduction

The most significant advantage that this technology provides to the user is the reduction of errors that may take place during the construction proves. By providing a virtual design on the field, it becomes easier to control the different processes and achieve a better output (Agarwal, 2016). Since error rectification reduces, the cost of material and workforce utilised for that rectification is reduced, that helps in reducing the overall overheads of a project (Agarwal, 2016).

3.2.2 Continued assistance

Pervasive AR is all about continuity instead of isolated tasks, this means that all the possible applications of this technologies should be integrated into a personalised single device or system which provides continued assistance to the user (Grubert*, et al* , 2017).

3.3 Possible applications of pervasive AR

Based on the literature possible applications of AR include: Design, visualisation of drawings and technical information onto the jobsite, and marketing.

3.3.1 Design

Spatial models can help the designer identify the flaws and rectify them at the design stage itself. Also, it can contribute to create innovative designs as the architect can see the structure in real time, which can help in various advantageous changes (Agarwal , 2016).

3.3.2 Visualisation of drawings and technical information onto the job site

The translation of drawings into a structure is not an easy task. It involves various steps of identification of different structural elements and subsequently constructing them. Since the project is envisaged in phases, it may so happen that errors might creep in during various stages (Agarwal , 2016). The visualisation of drawings into 3D structures requires the integration of AR with other technologies such as BIM, to enable context aware solutions based on 3D information. One example is the utilisation of AR to display the positioning and layout of underground infrastructure and to mitigate undesired damages (Schall*, et al* , 2009).

3.3.3 Marketing

Explaining a project to a person without a technical background is a problem that all projects have to face. Architectural drawings may be extraordinary, but they are still on a smaller scale and generally 2-D. Using the concept of AR, the client can be given a virtual tour of the project, with all the colours and the different views that can be observed for the project. This can lead to better marketing strategies for organizations (Agarwal , 2016).

4. Conclusions and Recommendations

In this paper, we addressed the concept of pervasive AR, which is a recently added theory in the field of visualisation in construction. This concept consists of continued context-aware assistance integrated into an AR solution. This paper aimed at finding literature-based barriers and drivers for implementing PAR in the construction industry as well as possible solutions derived from PAR. The main drivers for the implementation of PAR are error and cost reduction, and continued assistance; whereas the main barriers are cost, hardware issues and development of applications.

The implementation of PAR is promising since it could bring error reduction and consequently cost reduction into construction projects by providing continued assistance and context-aware suggestion to the work-force. Nevertheless, the cost of the technology is a crucial limitation for its implementation, as well as existing hardware issues that might need to be overcome before an actual implementation.

The implementation of this technology looks like the definite future for the construction industry, and although some present limitations might slow down its implementation, the possible applications are promising, such as visualisation of technical information on the jobsite, visualisation of spatial model for design and marketing.

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The Editors

Professor Ghassan Aouad is the President of Applied Science University in Bahrain and Past President of the Chartered Institute of Building. During his research career which spans over 25 years, he successfully supervised 24 PhD students, externally examined 52 PhD students, authored 3 major research books and co-authored one book, generated more than £10M in research funding as Principal Investigator and £8M as Co-Investigator, published 92 papers in top rated refereed journals, delivered more than 50 keynote speeches and invited lectures, and presented his work in more than 42 countries. In July 2016, Professor Aouad received an Honorary Doctorate of Technology from Loughborough University in the UK.

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